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Original article

Proprioceptive function after isolated single-bundle posterior cruciate ligament reconstruction with remnant preservation for chronic posterior cruciate ligament injuries



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ABSTRACT

Introduction: Posterior cruciate ligament (PCL) reconstruction using the remnant preserving technique may contribute to improved postoperative posterior stability, graft healing, and proprioception recovery. Although there have been several reports on remnant preserving PCL reconstruction, no study has yet evaluated the proprioceptive functions before and after PCL reconstruction with remnant preservation. The purpose of this study is to retrospectively evaluate the clinical outcomes and proprioceptive function after isolated single-bundle PCL reconstruction with remnant preservation for chronic PCL injuries.

Hypothesis: Isolated single-bundle PCL reconstruction with remnant preservation surgery for chronic PCL injuries provides satisfactory clinical outcomes and good recovery of the proprioceptive function.

Methods: Nineteen patients who had undergone isolated single-bundle PCL reconstruction with remnant preservation for chronic PCL injuries were followed up for more than 2 years. The posterior laxity was measured by the gravity sag view, stress radiography and the KT-2000 knee arthrometer. The proprioceptive function was defined as the threshold to detect passive motion (TTDPM).

Results: The average Lysholm score significantly improved from 63.7 ± 13.2 preoperatively to 94.4 ± 4.6 at final follow-up. The postoperative posterior laxity significantly improved. Regarding TTDPM, there were no significant differences between the preoperative score and the score at every given time point, regardless of the starting angles and the moving directions of the knees.

Conclusions: The proprioceptive function, defined as TTDPM, is maintained after single-bundle PCL reconstruction with remnant preservation, and the postoperative clinical scores and posterior laxity significantly improve.

Level of evidence: Level IV, therapeutic case series.

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1. Introduction

Reconstruction of the isolated posterior cruciate ligament (PCL) is recommended for patients with severe instability or disability due to PCL insufficiency. Thanks to recent innovations of arthroscopic surgical instruments and improved anatomical and biomechanical understandings of PCL [1], PCL reconstruction has gained in popularity. There are several types of PCL reconstruction, such as “single-bundle” [2], “double-bundle” [3], “transtibial” [4], or “tibial in-lay” [5] procedures.

The torn PCL usually demonstrates thick and abundant remnant fibers of both the PCL and the meniscomfemoral ligament. During PCL

reconstruction surgery, the remnant fibers are generally removed to obtain full visualization of the original ligament attachment site. However, PCL has been shown to include neural elements that may have beneficial effects on proprioceptive function [6]. In addition, the PCL remnants may provide some biomechanical stability to the knee [7]. Since the PCL remnants are likely to provide more rapid vascularization to the grafted tendon, PCL reconstruction with the remnant preserving technique may contribute to postoperative posterior stability, healing of the graft, and recovery of proprioception. No previous study has evaluated the proprioceptive functions before and after PCL reconstruction with remnant preservation [8–11]. The purpose of this study was to retrospectively evaluate the clinical outcomes and proprioceptive function after isolated single-bundle PCL reconstruction with remnant preservation for chronic PCL injuries. We hypothesized that isolated single-bundle PCL reconstruction with remnant preservation surgery for chronic

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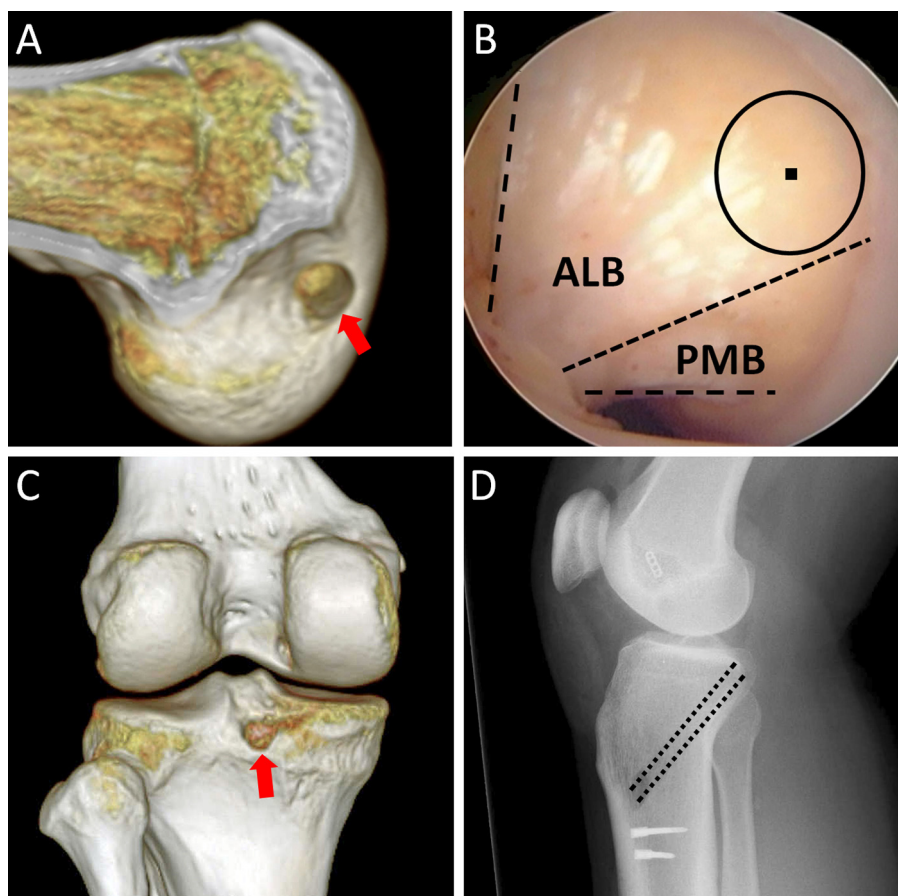


Fig. 1. A. Lateral view of a right medial femoral condyle reconstructed from CT image. Femoral bone tunnel is indicated by red arrow. B. Arthroscopic finding of a femoral attachment of PCL. The target point of femoral bone tunnel is the distal portion of the femoral attachment of the anterolateral bundle (ALB) which comes into contact with the anterior articular margin of the medial femoral condyle. C. Posterior view of a right knee reconstructed from CT image. Tibial bone tunnel is indicated by red arrow. D. Lateral radiograph of a right knee after operation. Tibial bone tunnel is indicated by dotted line.

PCL injuries provides sufficient clinical outcomes and good recovery of the proprioceptive function.

2. Methods

The study was reviewed and approved by the ethics committee of Hiroshima University. Written and signed informed consent was obtained from all patients.

PCL reconstruction at our institute was recommended for patients who, despite conservative treatment for at least 3 months, had severe posterior laxity of more than 8 mm of side-to-side difference in posterior displacement, as measured by a posterior stress radiograph. Fifty-three patients who underwent PCL reconstruction with remnant preservation using autogenous semitendinosus and gracilis tendons, performed between June 2004 and June 2010, were retrospectively enrolled in this study. Of these, 31 were excluded due to the fact that they met one of the following exclusion criteria:

- concomitant ACL injury (15 knees);
- other concomitant ligament injury (MCL 6 knees, LCL 7 knees);
- no sufficient PCL remnant (2 knees);
- severe associated fracture in the lower extremity (1 knee).

In addition, three patients were lost to follow-up, which left 19 patients who met the inclusion criteria and could be followed up for a minimum of 24 months. They consisted of 16 males and 3 females with a mean age of 27.9 (17–59) years at the time of

surgery. The average period from the initial injury to surgery was 20.1 (5–72) months. The average postoperative follow-up period was 27.1 (24–57) months. Causes of PCL injury were traffic accidents in 12 patients, sports-related injuries in 6 patients, and a falls in 1 patient. All procedures were performed by a senior specialist. The graft type (semitendinosus and gracilis tendon), methods of tibial and femoral fixation, and postoperative rehabilitation protocols were identical for each patient.

2.1. PCL augmentation procedure

Semitendinosus and gracilis tendons were harvested using an open-tendon stripper. These tendons formed a graft more than 8 mm in diameter and more than 75 mm in length by folding them in thirds or quarters. The proximal ends of the multi-stranded hamstring tendons were connected to an appropriately sized EndoButton CL loop (Acufex, Smith & Nephew, Mansfield, Massachusetts, US). The distal ends were mechanically connected to EndoButton Tape by suturing them several times to lengthen the graft.

Two portals (anterolateral portal and anteromedial portal) were created and an arthroscopic intra-articular examination was performed with a 30° oblique arthroscope. The posteromedial portal was created using a guide system [12].

A femoral bone tunnel was created in the inside-out fashion. Synovial and fat-like tissue on the femoral attachment of the PCL remnant was removed carefully to expose the fibers of the PCL bundles, which were preserved as much as possible. A headed

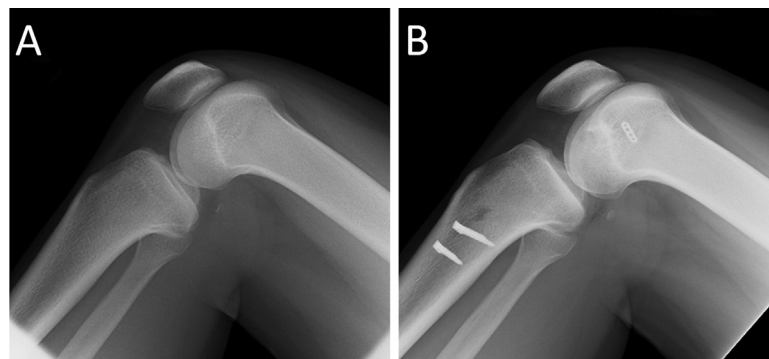


Fig. 2. Lateral radiograph of both knees flexed to 90° is taken with maximum manual stress from the radiographic gravity sag view. Preoperative posterior sagging (A) improved at the last follow-up (B).

cannulated reamer as a guide for femoral tunnel placement was placed at the distal portion of the femoral attachment of the antero-lateral bundle which comes into contact with the anterior articular margin of the medial femoral condyle (Figs. 1A and B). The 2.0-mm Kirschner wire was inserted through the reamer to serve as guide wire. After overdrilling with the 4.5-mm diameter EndoButton drill, the femoral bone socket was created using the above-mentioned reamer. The depth of the femoral socket was at least 15 mm (9 mm for the graft and 6 mm for the EndoButton flipping). A tibial bone tunnel was created using the Director PCL Tibial Aimer (Acufex, Smith & Nephew, Mansfield, Massachusetts, US) at 60° of the guide angle within the distal center portion of the tibial insertion of PCL which comes into contact with the posterior edge of the retrospinal surface (Figs. 1C and D). This tunnel creation method-facilitated the preservation of remnant and moreover the graft passage since the famous killer turn angle became wide and preserved remnant protected the edge of tunnel aperture [13]. After the graft was passed through the tibial bone tunnel to the femoral socket, the EndoButton was flipped outside the medial cortex of the femur. The distal EndoButton Tape of the graft was fixed with double spike staples at 90° of the knee in a flexed position by applying manual maximum tension to the tape with the tibia in anterior drawer.

2.2. Postoperative rehabilitation

The knee was immobilized for 1 week, braced in extension. Active quadriceps exercises were recommended as soon as possible after the operation. The range of motion exercises were started using a continuous passive motion device 1 week postoperatively. Partial weight bearing was permitted after 3 weeks. Jogging was initiated after four months and sports activities resumed at 12 months postoperatively.

2.3. Clinical and radiographic and functional evaluation

The patients were followed up for clinical, radiographic and functional evaluation. Clinical evaluation was based on the Lysholm knee score. Radiographic evaluations were performed including the measurement of the bilateral posterior stress radiograph with a maximum manual stress and the radiographic gravity sag view [14], with the knees flexed to 90° (Fig. 2). In addition to the radiographs, the KT-2000 knee arthrometer test was performed on each patient in the standard fashion, and the side-to-side differences between the reconstructed and contralateral knees were recorded. These evaluations were performed before surgery; at 3 and 6 months after surgery; and at every 6 months thereafter.

Functional evaluation of the proprioceptive function as the threshold to detect passive motion (TTDPM) was performed pre-operatively and at 6, 12, and 24 months after surgery using a

proprioception testing apparatus (Sensor Ouyou, Hiroshima, Japan; Fig. 3), as described in previous studies [15–17]. Patients were tested in a seated position and blindfolded, and had their ears covered to minimize visual and auditory cues. A pneumatic boot was placed below the knee joint to keep the ankle in the neutral position and to minimize cutaneous sensation. The left limbs of each subject were measured first, regardless of the operated side. Evaluation was started from 15° and 45° of knee flexion. The apparatus moved the



Fig. 3. Proprioceptive testing apparatus. Patients are tested in a seated position, blindfolded and have their ears covered to minimize visual and auditory cues. The testing limb is put into a pneumatic boot to keep the ankle in the neutral position and minimize cutaneous sensation. A hand-held switch enables each subject to stop the movement when they perceive it as joint motion.

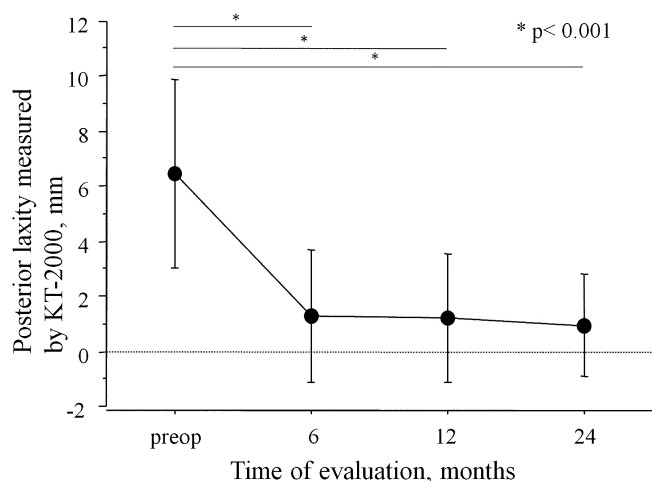


Fig. 4. Posterior laxity measured by KT-2000. There is a statistically significant difference between the preoperative posterior laxity and other time points, showing postoperative improvement of total displacement of the tibia ($P < 0.001$).

knee into both flexion and extension at a constant angular velocity of $0.2^\circ/\text{s}$; this slow speed was chosen based on the previous study reported by Shidahara et al. [18]. Four measurements were conducted in a random sequence, thus measuring kinesthesia once for each starting position and direction of the movement. Resting times between each measurement were set randomly within 10 seconds to minimize patient guessing. Patients practiced twice before the initial measurement without warming up. The reaction times that the subject perceived the motion and took to press the button were recorded as the TTDPM.

2.4. Statistical analysis

The Wilcoxon signed rank test was used for paired comparison of joint laxity or the Lysholm score, and proprioceptive function tests. The value of $P < 0.05$ was regarded as significant. All of the statistical analysis was done using Statview 5.0® (SAS Institute; Cary, North Carolina, US).

3. Results

The average Lysholm scores were 63.7 ± 13.2 preoperatively and 94.4 ± 4.6 at the last follow-up, and this difference was statistically significant ($P < 0.001$). At the end point evaluation, the clinical results were classified as excellent in 12 patients (63.2%) and good in 7 (36.8%), according to Lysholm classification score (Table 1).

The posterior laxity, as measured by the radiographic gravity sag view and posterior stress view, was significantly improved as shown in Table 2. The posterior laxity, as measured by the KT-2000 knee arthrometer preoperatively, at 6, 12, 24 months after surgery was 6.4 ± 3.4 , 1.3 ± 2.4 , 1.2 ± 2.3 , 1.0 ± 1.8 mm, respectively (Fig. 4). There were significant differences between the preoperative posterior laxity and that of the other follow-up periods as shown by both the measurements of the radiographic gravity sag view and posterior stress view and of the KT-2000 knee arthrometer.

The proprioceptive function measured as the TTDPM is shown in Figs. 5 and 6. There were no significant differences between preoperative and any follow-up point regardless of the starting angles and the moving directions of the knees, or between reconstructed knee and contralateral knee even preoperatively.

4. Discussion

This study demonstrated that PCL reconstruction with remnant preservation provided favorable postoperative stability and functional scores. Almost all proprioceptive function measured by the TTDPM was retained after the reconstruction. To the best of our knowledge, this is the first study that clarified the proprioceptive function after PCL reconstruction with remnant preservation.

As for the joint laxity after PCL reconstruction, Kim et al. [19] reported a systematic review of clinical results of arthroscopic single-bundle transtibial PCL reconstruction in 2011. According to their review, the average posterior laxity after PCL reconstruction varied from 1.96 mm to 5.9 mm, which was significantly improved from the preoperative values (8.38–12.3 mm). Our current study shows that posterior laxity (1.0 ± 1.8 mm) was somewhat better or at least equal to measurements of previous reports.

After Schultz et al. [20] reported the existence of mechanoreceptors in the human cruciate ligament, it was recognized that the cruciate ligaments have important afferent proprioceptive roles through those mechanoreceptors. Recently, attention has been paid to remnant preserving techniques in ACL reconstruction [21,22]. According to these reports, preserved remnant fibers may contribute to the maintenance or improvement of the postoperative proprioceptive function, biomechanical joint stability, and more rapid revascularization of the grafted tendon.

PCL reconstruction using the remnant preserving technique has been reported by several authors. In 2006, Ahn et al. [23] reported the clinical results of 61 patients who underwent a transtibial single-bundle PCL reconstruction with the remnant preserving technique. Their second-look arthroscopy revealed complete healing and graft integration and that the killer turn effect can be reduced by preserving the original PCL fibers. In 2012, Kim et al. [24] compared the conventional and remnant preserving transtibial single-bundle PCL reconstructions. They concluded that although remnant preservation did not provide better posterior stability or clinical outcomes, the activity-related outcomes were better in remnant preserving PCL reconstructions than in techniques without.

Although proprioceptive function of the PCL is a critical issue, there have been few reports on this topic. Clark et al. [25] and Safran et al. [16] demonstrated a significant reduction of proprioceptive function as measured by the TTDPM in PCL injured knees compared with contralateral healthy knees. Our results show that the preoperative TTDPM in both healthy and PCL injured knees do not differ significantly, and that the postoperative TTDPM in the PCL reconstructed knee is maintained throughout the postoperative follow-up. One possible explanation of the fact that the preoperative TTDPM of PCL injured knees does not differ from that in healthy knees is that proprioceptive afferent information can be transferred to the central nervous system through tensioned injured PCL in the sagged knee because the PCL remnant usually maintains synovial continuity more than the ACL remnant. Maintenance of postoperative proprioceptive function measured by the TTDPM may be due to preservation of the PCL remnant in this reconstruction.

As for the proprioceptive function after PCL reconstruction, Adachi et al. [14] reported on the clinical and proprioceptive function after PCL reconstruction. Interestingly, they stated that although joint stability improved postoperatively and was maintained over 2 years after reconstruction, the joint position sense worsened just after the reconstruction and it gradually recovered from 18 months after surgery, but did not recover to the same level as in the contralateral normal knee even after 24 months post-surgery. It is worth noting that the discrepancy between our results and the results they reported for the proprioceptive function involved the preservation of the PCL remnant. In their PCL reconstruction, the PCL remnant with surrounding synovium was

Table 1
Clinical results of single-bundle PCL reconstruction with remnant preservation.

	Preoperative (n = 19)	Last follow-up (n = 19)	P-value
<i>Lysholm score (mean ± SD)</i>	63.7 ± 13.2	94.4 ± 4.6	<001
Excellent (95–100)	0	12 (63.2%)	–
Good (85–94)	1 (5.3%)	7 (36.8%)	–
Fair (65–84)	8 (42.1%)	0	–
Poor (<65)	10 (52.6%)	0	–

Table 2
Results of single-bundle PCL reconstruction with remnant preservation.

	Preoperative (n = 19)	Last follow-up (n = 19)	P-value
<i>Gravity sagging view (mean ± SD)</i>	10.6 ± 2.8	2.2 ± 0.8	<001
<3 mm	0	13 (68.4%)	–
3–5 mm	1 (5.2%)	6 (31.6%)	–
6–10 mm	9 (47.4%)	0	–
>10 mm	9 (47.4%)	0	–
<i>Stress view (mean ± SD)</i>	11.6 ± 2.9	2.3 ± 1.0	<001
<3 mm	0	12 (63.2%)	–
3–5 mm	0	7 (36.8%)	–
6–10 mm	10 (52.6%)	0	–
>10 mm	9 (47.4%)	0	–

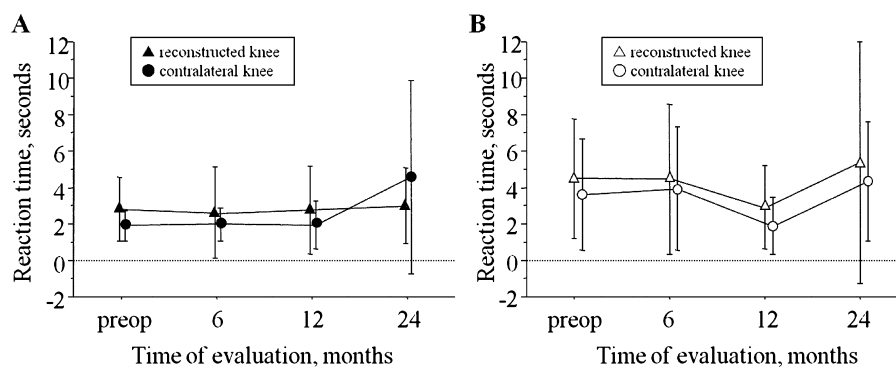


Fig. 5. The temporal changes in the mean threshold to detect passive motion (TTDPM) compares the PCL-reconstructed knees with contralateral knees moving into extension at 15° (A) and flexion at 15° (B). There are no statistically significant differences at any time points.

completely removed, which might result in postoperative loss of joint position sense through loss of mechanoreceptors including the PCL remnant. So every attempt should be made to preserve the important mechanoreceptors in the PCL remnant, to avoid a lack of postoperative proprioceptive function.

We acknowledge some limitations of our study. First, this is not a randomized comparative study with a small number of patients and short follow-up. Therefore, we cannot conclude any superiority of PCL reconstruction with remnant preservation over any other. We started the procedure of PCL reconstruction with remnant

preservation for all patients, with the expectation that the remnant would retain some function from 2004. For this reason, it is ethically difficult to conduct a randomized comparative study. Second, the proprioceptive function, as the threshold for detection of passive motion, was evaluated only at 15° and 45° of knee flexion. For the evaluation of proprioceptive function of the PCL, evaluation at a deeper flexion angle of the knee may be appropriate. Third, our study does not enable final conclusions to be drawn about all potential benefits of vascular or biomechanical contributions of PCL remnant preservation.

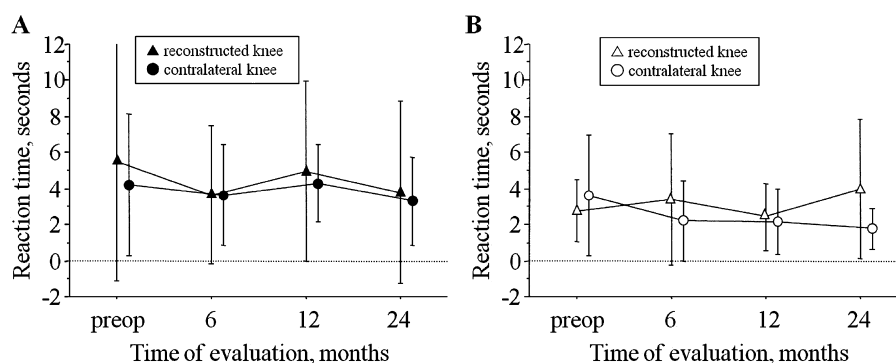


Fig. 6. The temporal changes in the mean TTDPM compares the PCL-reconstructed knees with contralateral knees moving into extension at 45° (A) and flexion at 45° (B). There are no statistically significant differences at any time points.

5. Conclusion

PCL reconstruction with remnant preservation provides favorable postoperative stability and functional scores. Proprioceptive function measured by the TTDPM is retained after this reconstruction.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References

- [1] Amis AA, Gupte CM, Bull AM, Edwards A. Anatomy of the posterior cruciate ligament and the meniscomfemoral ligaments. *Knee Surg Sports Traumatol Arthrosc* 2006;14:257–63.
- [2] Jackson WF, van der Tempel WM, Salmon LJ, Williams HA, Pinczewski LA. Endoscopically-assisted single-bundle posterior cruciate ligament reconstruction: results at minimum ten-year follow-up. *J Bone Joint Surg Br* 2008;90:1328–33.
- [3] Kim SJ, Choi CH, Kim HS. Arthroscopic posterior cruciate ligament tibial inlay reconstruction. *Arthroscopy* 2004;20(Suppl. 2):149–54.
- [4] Shino K, Nakagawa S, Nakamura N, Matsumoto N, Toritsuka Y, Natsu-ume T. Arthroscopic posterior cruciate ligament reconstruction using hamstring tendons: one-incision technique with Endobutton. *Arthroscopy* 1996;12:638–42.
- [5] Berg EE. Posterior cruciate ligament tibial inlay reconstruction. *Arthroscopy* 1995;11:69–76.
- [6] Katonis PG, Assimakopoulos AP, Agapitos MV, Exarchou EI. Mechanoreceptors in the posterior cruciate ligament. Histologic study on cadaver knees. *Acta Orthop Scand* 1991;62:276–8.
- [7] Hewett TE, Noyes FR, Lee MD. Diagnosis of complete and partial posterior cruciate ligament ruptures. Stress radiography compared with KT-1000 arthrometer and posterior drawer testing. *Am J Sports Med* 1997;25:648–55.
- [8] Ahn JH, Yang HS, Jeong WK, Koh KH. Arthroscopic transtibial posterior cruciate ligament reconstruction with preservation of posterior cruciate ligament fibers: clinical results of minimum 2-year follow-up. *Am J Sports Med* 2006;34:194–204.
- [9] Jung YB, Jung HJ, Song KS, Kim JY, Lee HJ, Lee JS. Remnant posterior cruciate ligament-augmenting stent procedure for injuries in the acute or subacute stage. *Arthroscopy* 2010;26:223–9.
- [10] Lee KH, Jung YB, Jung HJ, Jang EC, Song KS, Kim JY, et al. Combined posterolateral corner reconstruction with remnant tensioning and augmentation in chronic posterior cruciate ligament injuries: minimum 2-year follow-up. *Arthroscopy* 2011;27:507–15.
- [11] Yoon KH, Bae DK, Song SJ, Lim CT. Arthroscopic double-bundle augmentation of posterior cruciate ligament using split Achilles allograft. *Arthroscopy* 2005;21:1436–42.
- [12] Ochi M, Adachi N, Sumen Y, Uchio Y, Iwasa J. A new guide system for posteromedial portal in arthroscopic knee surgery. *Arch Orthop Trauma Surg* 1998;118:25–8.
- [13] Greiner P, Magnussen RA, Lustig S, Demey G, Neyret P, Servien E. Computed tomography evaluation of the femoral and tibial attachments of the posterior cruciate ligament in vitro. *Knee Surg Sports Traumatol Arthrosc* 2011;19:1876–83.
- [14] Adachi N, Ochi M, Uchio Y, Iwasa J, Ishikawa M, Shinomiya R. Temporal change of joint position sense after posterior cruciate ligament reconstruction using multi-stranded hamstring tendons. *Knee Surg Sports Traumatol Arthrosc* 2007;15:2–8.
- [15] Reider B, Arcand MA, Diehl LH, Mroczek K, Abulencia A, Stroud CC, et al. Proprioception of the knee before and after anterior cruciate ligament reconstruction. *Arthroscopy* 2003;19:2–12.
- [16] Safran MR, Allen AA, Lephart SM, Borsa PA, Fu FH, Harner CD. Proprioception in the posterior cruciate ligament-deficient knee. *Knee Surg Sports Traumatol Arthrosc* 1999;7:310–7.
- [17] Skinner HB, Barrack RL, Cook SD. Age-related decline in proprioception. *Clin Orthop Relat Res* 1984;184:208–11.
- [18] Shidahara H, Deie M, Niimoto T, Shimada N, Toriyama M, Adachi N, et al. Prospective study of kinesthesia after ACL reconstruction. *Int J Sports Med* 2011;32:386–92.
- [19] Kim YM, Lee CA, Matava MJ. Clinical results of arthroscopic single-bundle transtibial posterior cruciate ligament reconstruction: a systematic review. *Am J Sports Med* 2011;39:425–34.
- [20] Schultz RA, Miller DC, Kerr CS, Micheli L. Mechanoreceptors in human cruciate ligaments. A histological study. *J Bone Joint Surg Am* 1984;66:1072–6.
- [21] Adachi N, Ochi M, Uchio Y, Sumen Y. Anterior cruciate ligament augmentation under arthroscopy. A minimum 2-year follow-up in 40 patients. *Arch Orthop Trauma Surg* 2000;120:128–33.
- [22] Ochi M, Adachi N, Uchio Y, Deie M, Kumahashi N, Ishikawa M, et al. A minimum 2-year follow-up after selective anteromedial or posterolateral bundle anterior cruciate ligament reconstruction. *Arthroscopy* 2009;25:117–22.
- [23] Ahn JH, Nha KW, Kim YC, Lim HC, Nam HW, Wang JH. Arthroscopic femoral tensioning and posterior cruciate ligament reconstruction in chronic posterior cruciate ligament injury. *Arthroscopy* 2006;22:341 [e341–4].
- [24] Kim SJ, Kim SH, Chun YM, Hwang BY, Choi DH, Yoon JY. Clinical comparison of conventional and remnant-preserving transtibial single-bundle posterior cruciate ligament reconstruction combined with posterolateral corner reconstruction. *Am J Sports Med* 2012;40:640–9.
- [25] Clark P, MacDonald PB, Sutherland K. Analysis of proprioception in the posterior cruciate ligament-deficient knee. *Knee Surg Sports Traumatol Arthrosc* 1996;4:225–7.